

ATW and the Advanced Fuel Cycle Initiative

**Dr. Denis E. Beller
University Programs Leader
Los Alamos National Laboratory**

LA-UR-02-6772 Approved for public
release; distribution is unlimited.



Through the AAA-AFC Program, the U.S. has joined international efforts



**to evaluate the potential of
Partitioning & Transmutation
along with advanced nuclear fuel cycles**

Genesis of the ATW-AAA-AFC Project

¥ LANL ATW LDRD (~\$10 M FY90-98)

—molten salt ATW → Pb-Bi-cooled ATW

¥ DOE-EM ATW Roadmap (\$4.5 M FY99)

¥ DOE-NE ATW R&D Project (\$9 M FY00)

¥ NE ATW + DP APT → AAA
(\$34 M FY01 → \$50 M FY02)

¥ AAA → AFCI (\$78 M FY03)

Systems modeling projects future U.S. inventory of used fuel

¥ ATW Roadmap: 2030s → 87,000 tn

¥ Life extension: 2050s → 144,000 tn

¥ NEI Vision 2020:

new plants → new waste

—2030s: 120,000 tn

—2050s: more than 180,000 tn

What will we do with it?

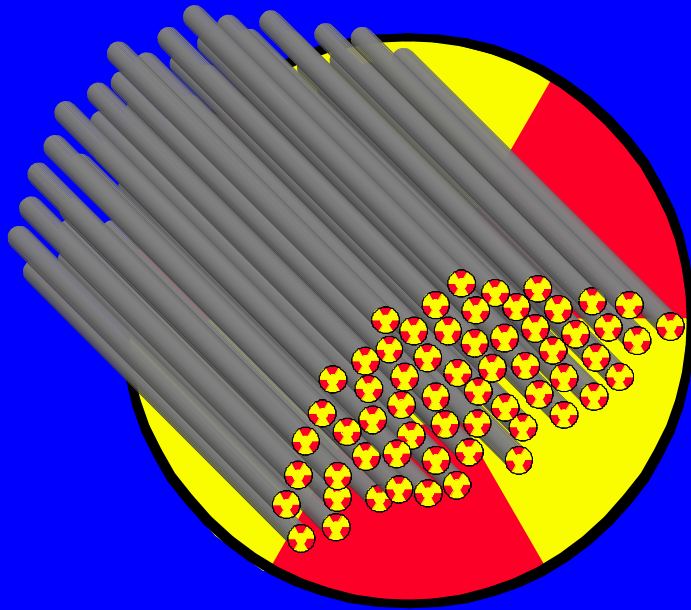
Options for disposal of nuclear waste

¥ once-through fuel cycle, or

¥reduce, reuse, and recycle

- MOX-fueled LWRs or HTGCRs
- Fast reactors (includes breeders)
- Accelerator-driven transmutation

Today's option: once-through fuel cycle



Repository

Direct disposal faces many challenges

- ¥ Political opposition**
- ¥ Public acceptance**
- ¥ Licensing and regulatory concerns**
- ¥ Uncertainty in projecting out for hundreds of thousands of years**

Transmutation of waste offers potential solutions to these challenges

Most long-term hazards are due to 1.1% of the used nuclear fuel

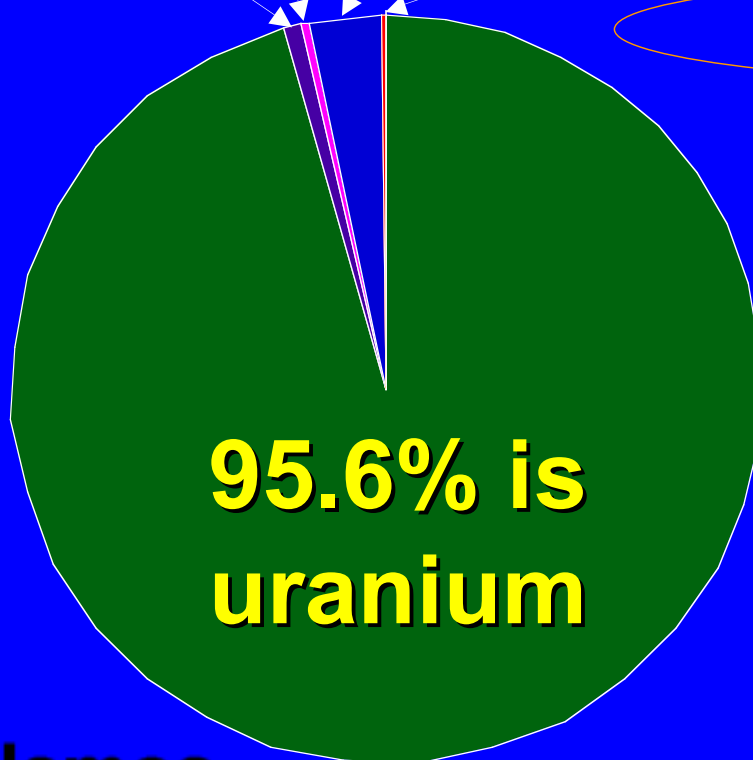
0.1% minor actinides

0.9% plutonium

3% stable or short-lived fission products

0.3% cesium and strontium

0.1% iodine and technetium



- uranium
- plutonium
- minor actinides
- Stable or short-lived fission products
- cesium & strontium
- Iodine
- Technetium

ATW can reduce projected doses, but defense waste reduces ATW impact

Impact on dose is reduced to about a factor of 10

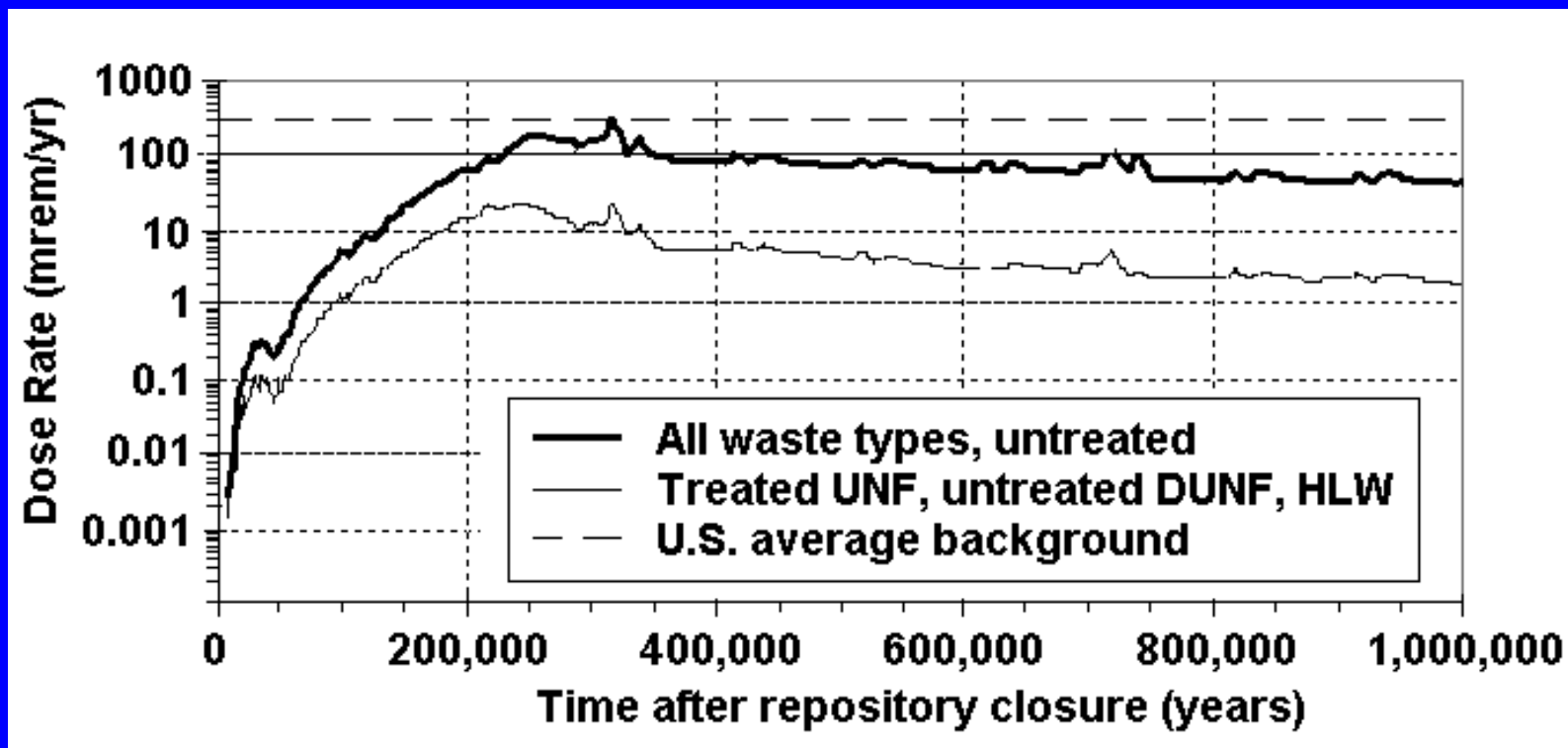


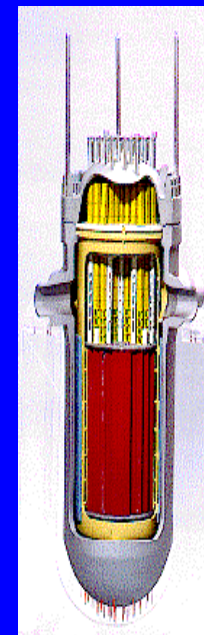
Figure 5.3. Individual Dose Rate (Adult, 20 km Distance, All Exposure Pathways) Comparison for the First Million Years after Repository Closure

Transmutation means Nuclear Transformation

- ¥ changes the contents of the nucleus (protons and/or neutrons)
- ¥ natural (decay) or driven
- ¥ since before World War II - it's Not Hard!



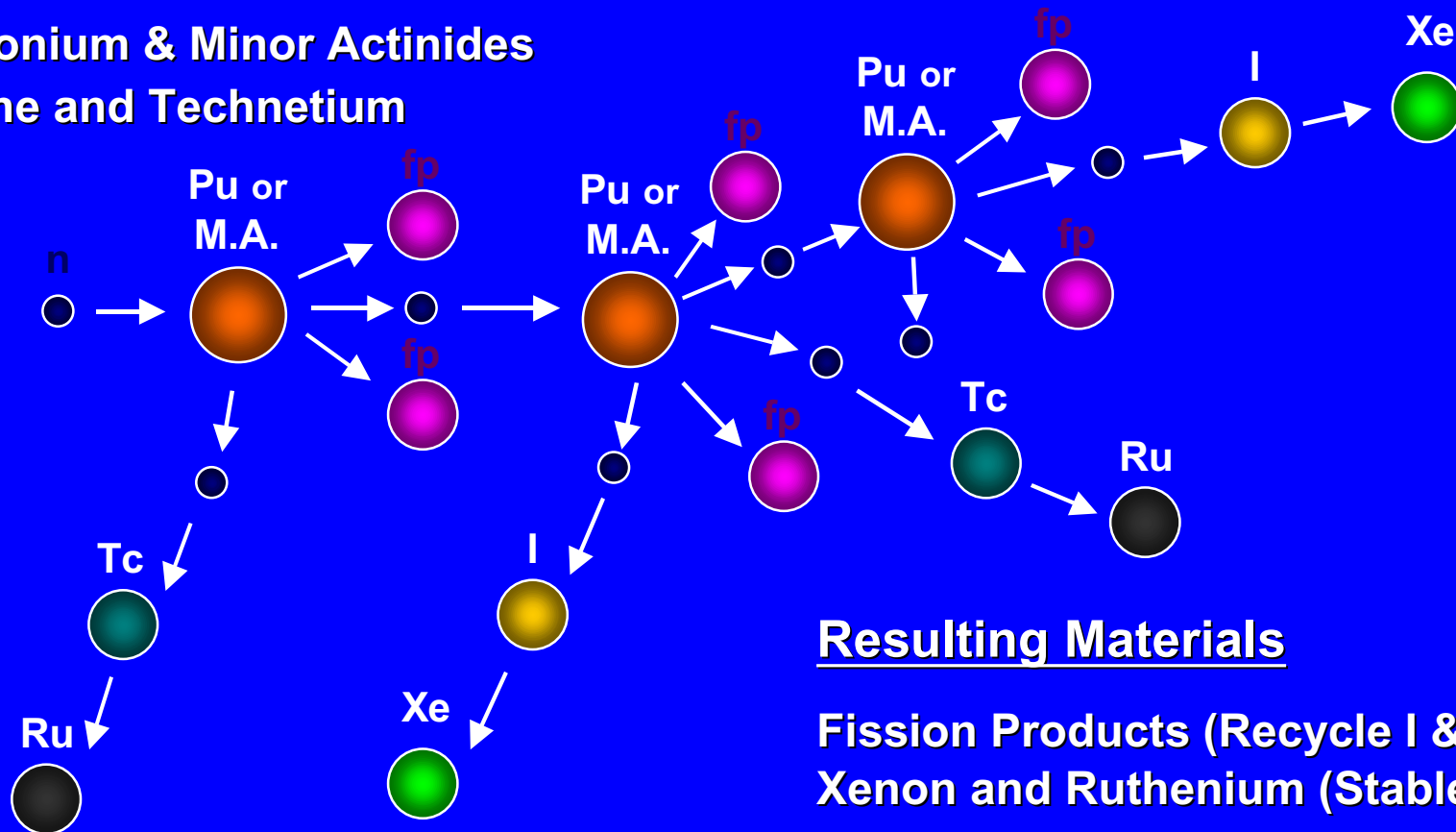
*Turn lead into
gold? Just
need a source
of neutrons .*



Pu and MA are fissioned, excess neutrons convert I and Tc to stable isotopes

Initial Materials

Plutonium & Minor Actinides
Iodine and Technetium



Resulting Materials

Fission Products (Recycle I & Tc)
Xenon and Ruthenium (Stable)

The challenge is to transmute effectively:

thorough, clean, safe, and cost-effective

¥ near 100% conversion

¥ low losses

¥ accident free

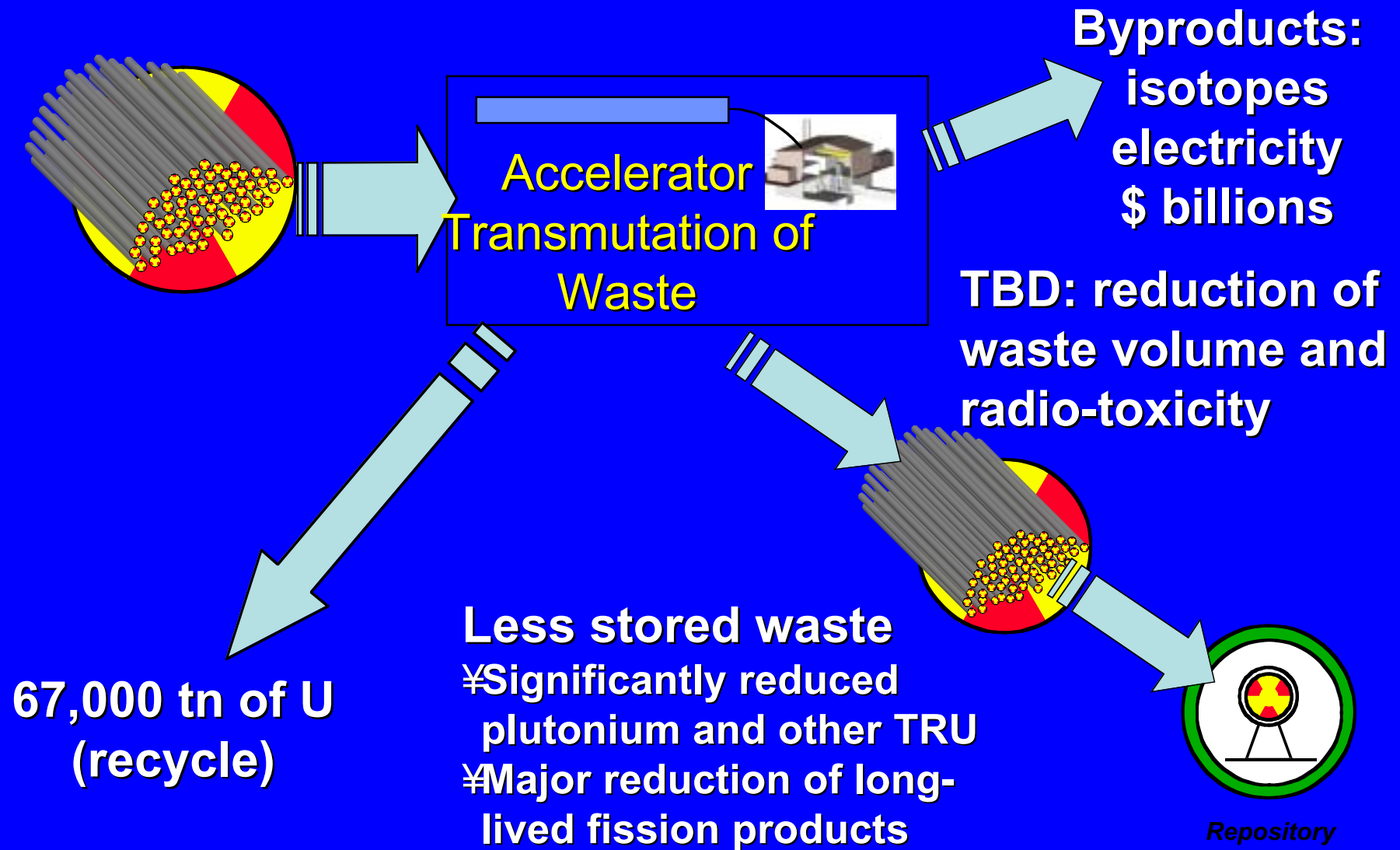
¥ reduce waste toxicity and volume

¥ minimal impact to cost of the nuclear fuel cycle

The Transmutation Strategy:

- ¥ Partition used nuclear fuel
- ¥ Discard uranium and stable elements
- ¥ Form transmutation fuel from long-lived radionuclides
- ¥ Transmute long-lived radionuclides into short-lived or stable isotopes
- ¥ Manage remaining short-lived wastes for just a few hundred years

ATW Technology Can Lead to Reductions of Nuclear Waste



ATW subcritical capability adds flexibility

¥ Nuclear systems have always operated critical

¥ Subcritical capability adds flexibility

- Can drive systems with low fissile content or high non-fissile burden
- operate with fuel that could make critical systems unstable
- compensate for large uncertainties or reactivity swings

Subcritical operation option addresses fuel cycle issues

- ¥ jump-start systems with insufficient fissile content**
- ¥ support advanced fuel cycles by transmuting wastes**
- ¥ close-down cycles with depleted fissile content**

To do this, ATW includes three major technology elements:

1) Separations & Waste Forms

- aqueous or molten salt chemistry**
- glass, ceramic, or metal waste forms**

2) Accelerators

- linacs or cyclotrons**

3) Subcritical Transmuters

- fast, metal, gas, molten salt, thermal**

separations and Waste Forms

Separations processes are being investigated at ANL and LANL

¥ Aqueous: UREX

- may be preferred for separation of used LWR fuel**
- does not separate Pu from MA**

¥ Pyro-processing

- similar to IFR**
- for used ATW fuel**

¥ Others (FLEX,)

Partitioning can also provide stable waste forms

- ¥ Problem isotopes are separated, then
- ¥ some are transmuted,
- ¥ while others can be combined to create long-lived, non-hazardous waste forms
 - optimum repository performance impact
 - combine some with massive amounts of zirconium
 - combine some in vitrified waste

Accelerators

Accelerators will produce powerful beams of high-energy particles

¥ 600 to 1000 MeV protons

¥ mA of current

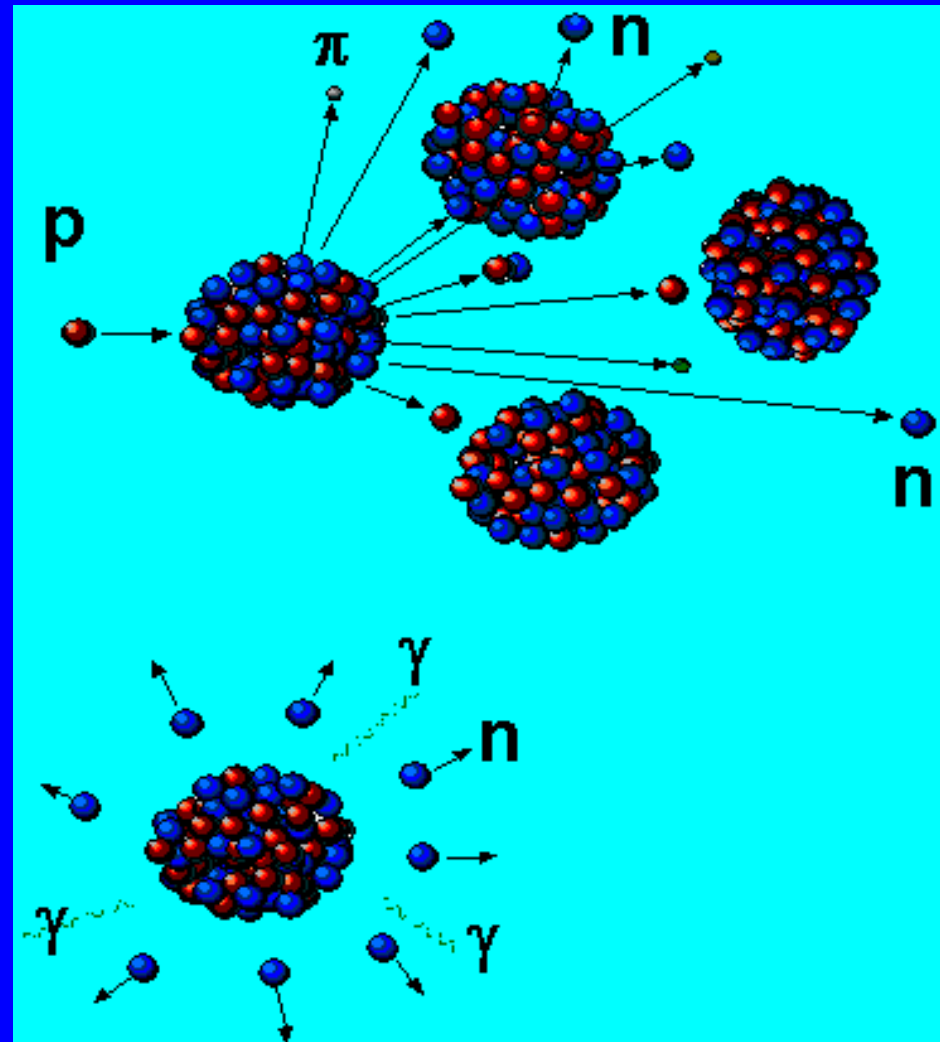
¥ product is MW of beam power

¥ big and expensive

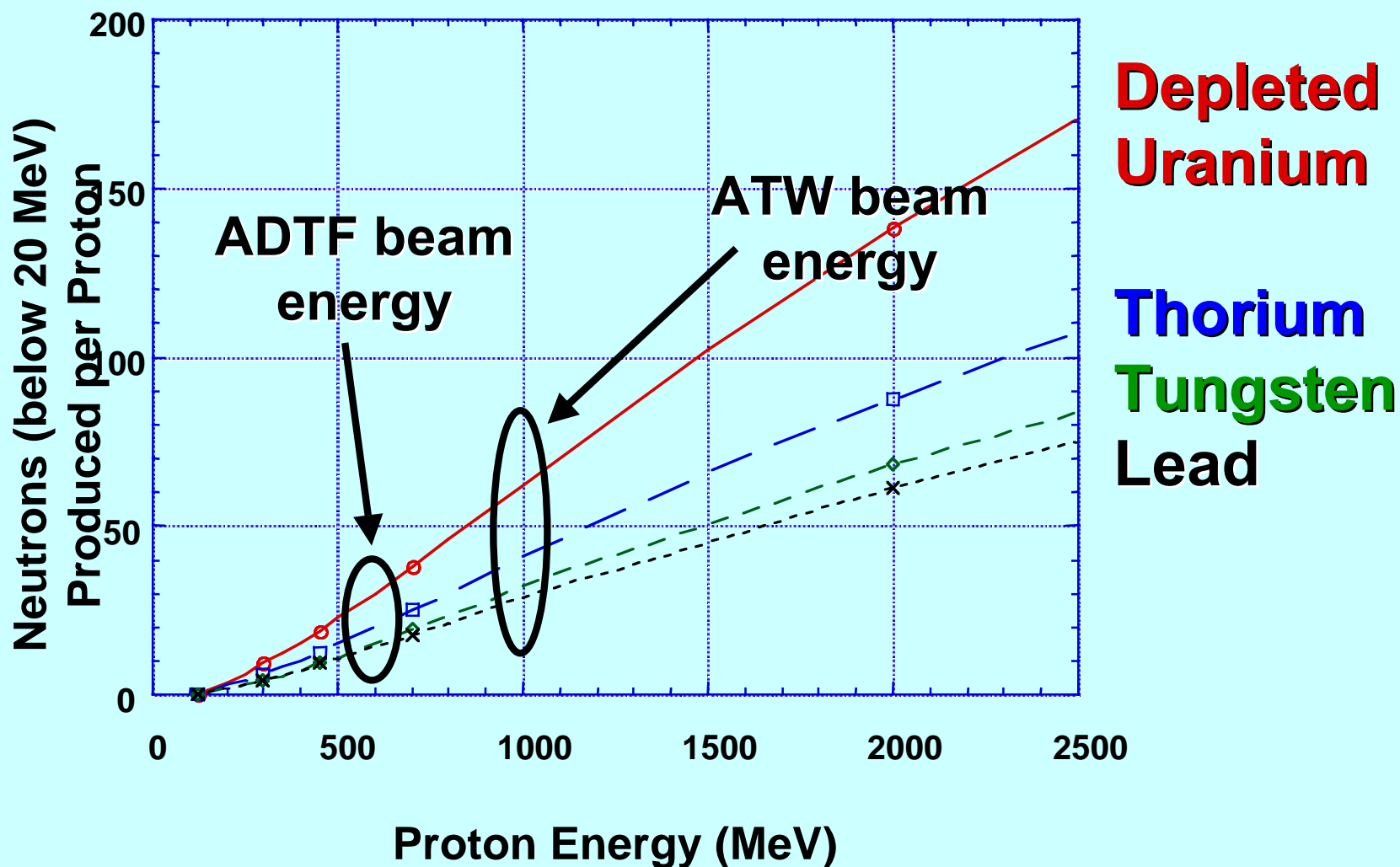
¥ how to turn that into neutrons for spallation?

Spallation & evaporation produce neutrons

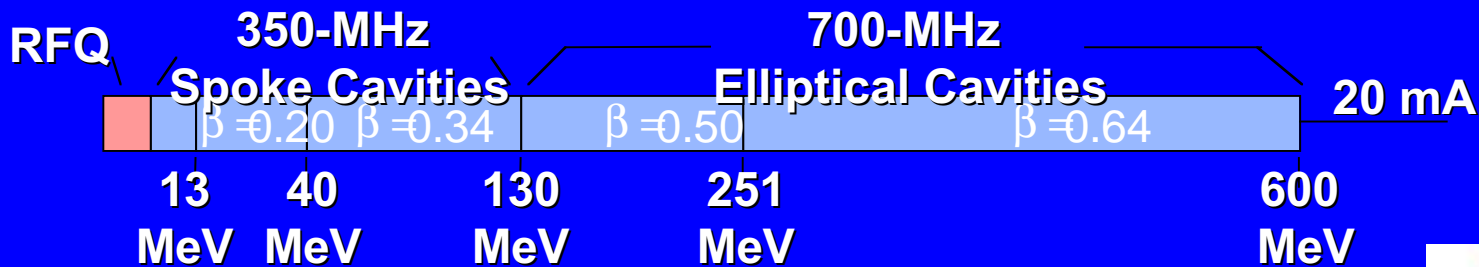
- ≠ protons strike heavy nuclei
- ≠ knocked-out particles create a cascade
- ≠ residual nuclei cool off by evaporation



Heavier target materials yield more neutrons per proton

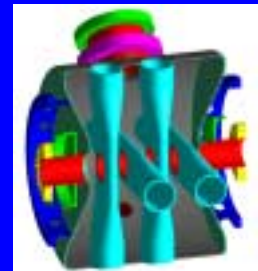


Components for a 12-MW proton beam

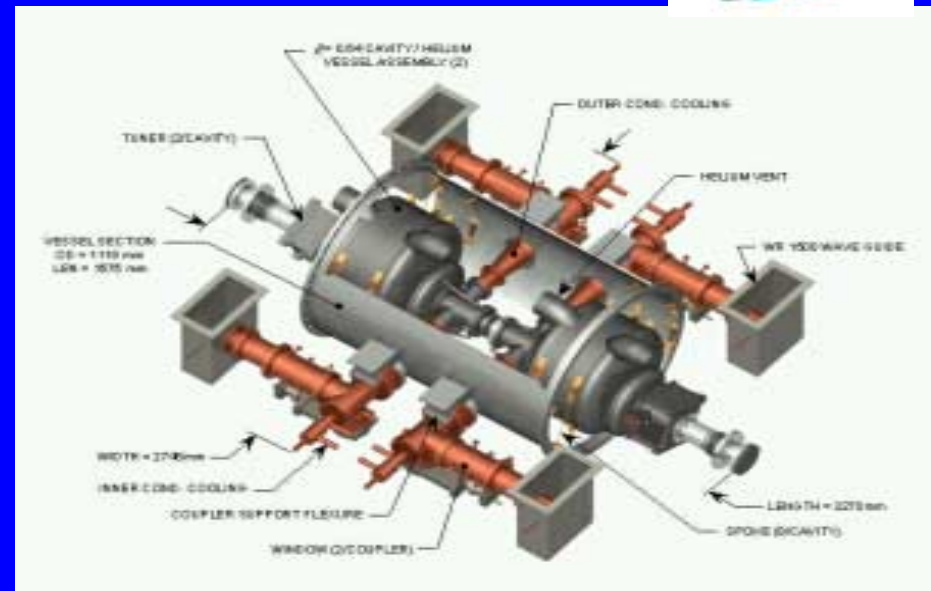


100-mA H⁺ injector including LEBT

$\beta = 0.125$, 5-GAP, 350 MHz superconducting spoke cavity



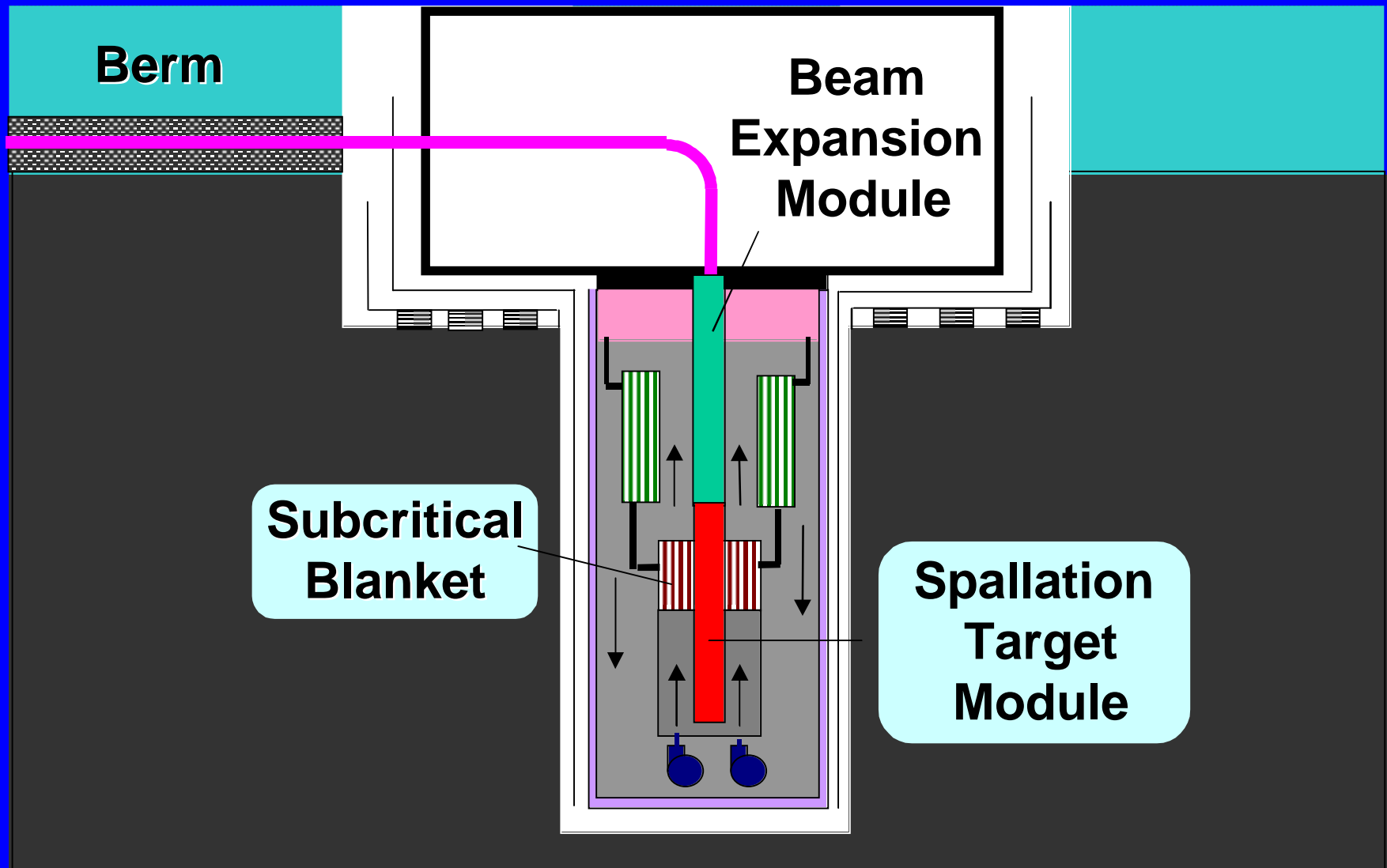
6.7 MeV RFQ with injector rolled back



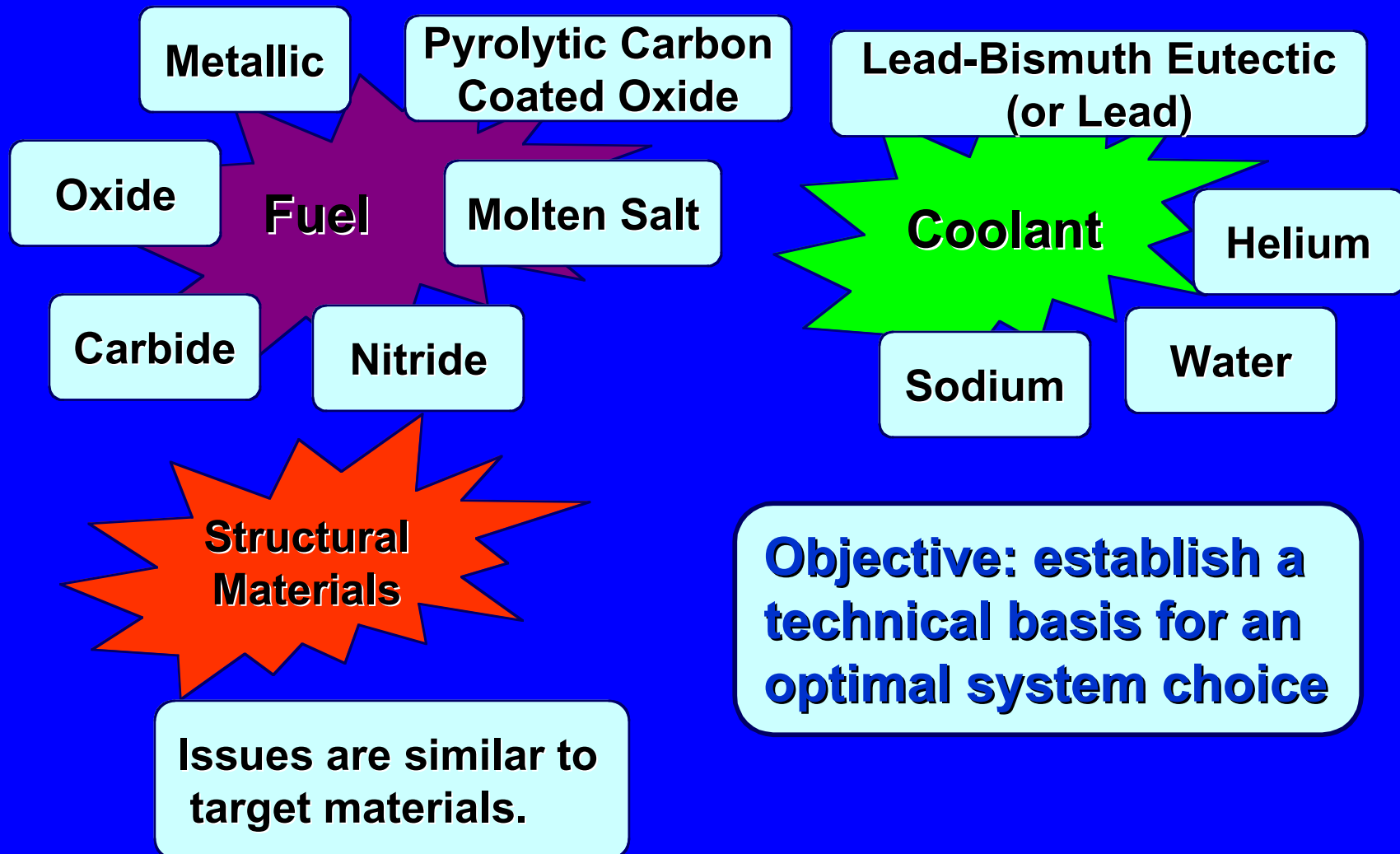
Two-cavity superconducting cryomodule isometric

Transmuters (Targets & Blankets)

ATW beam expansion and spallation target modules in ATW transmuter

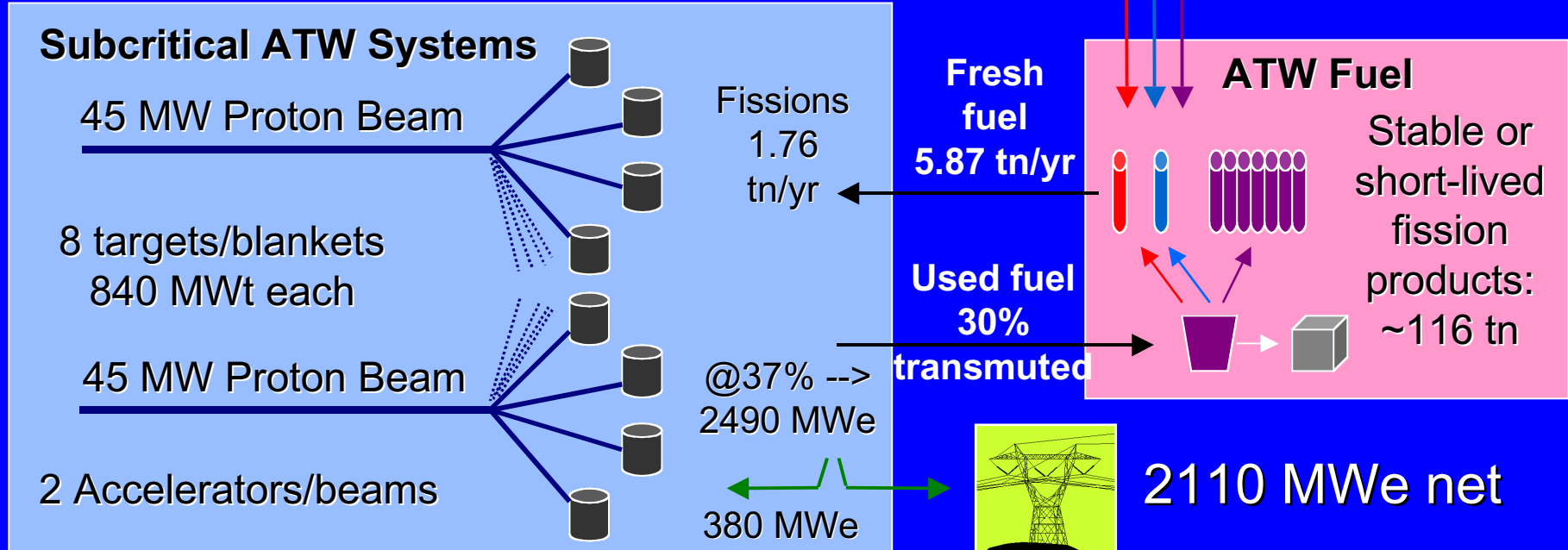
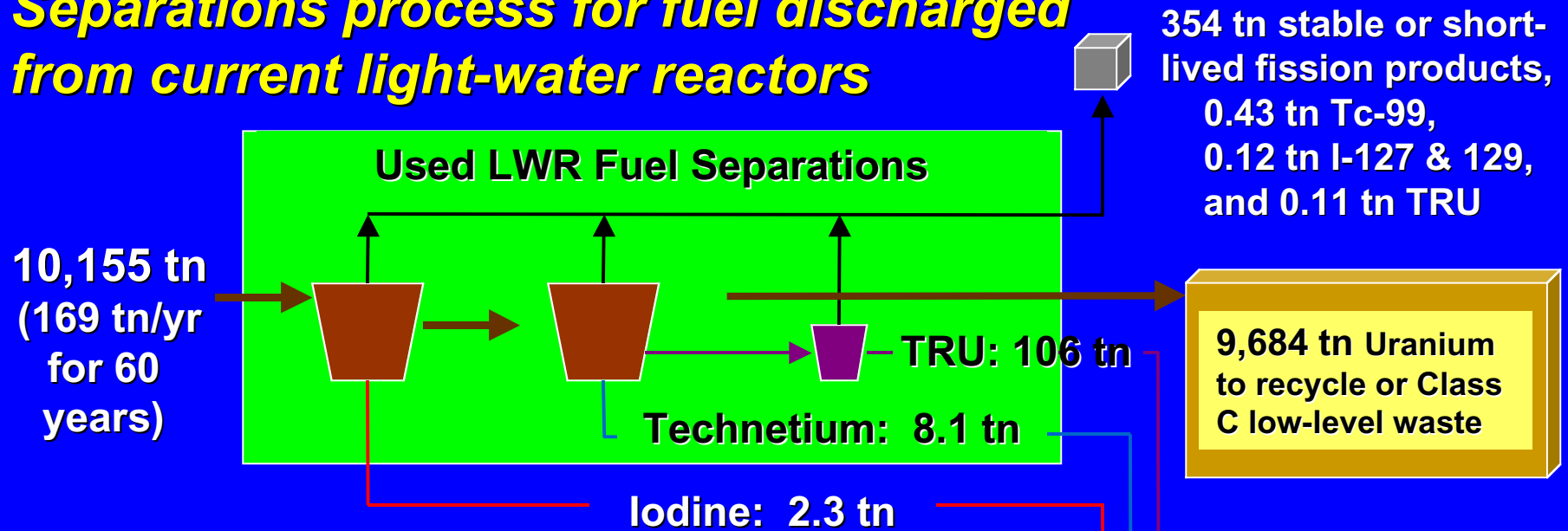


For the transmuter, the major challenge is fuel development

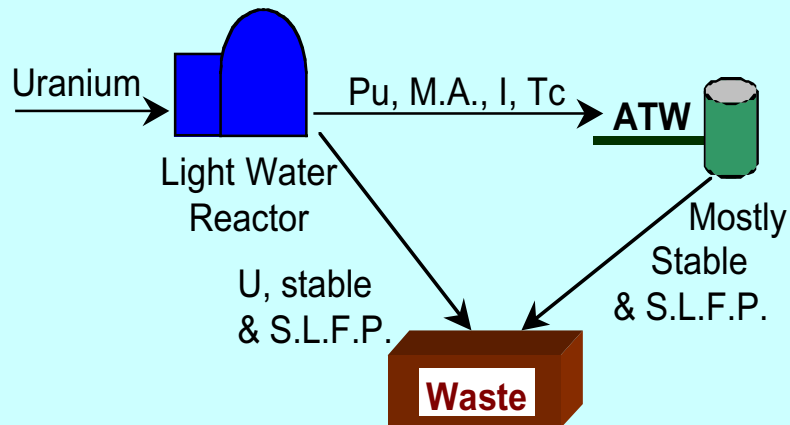


ATW Systems and Scenarios

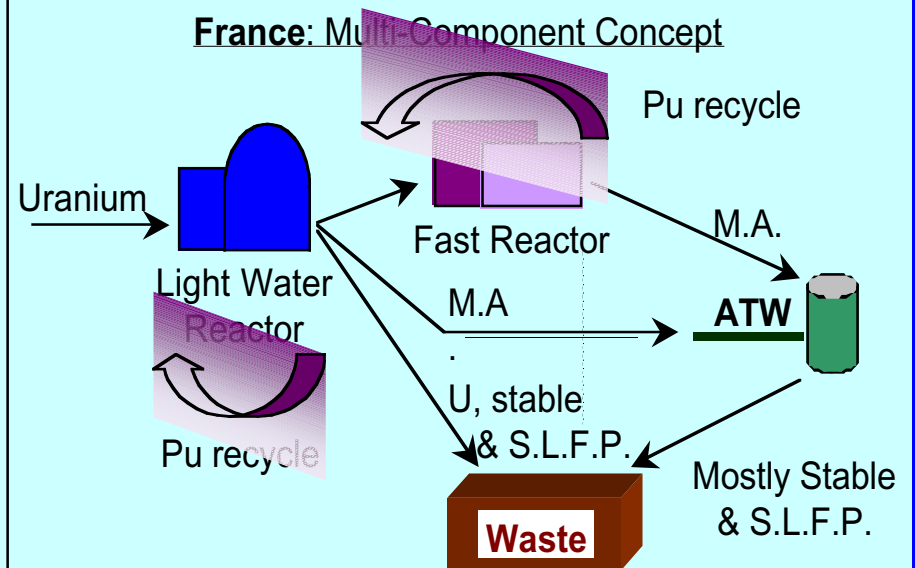
Separations process for fuel discharged from current light-water reactors



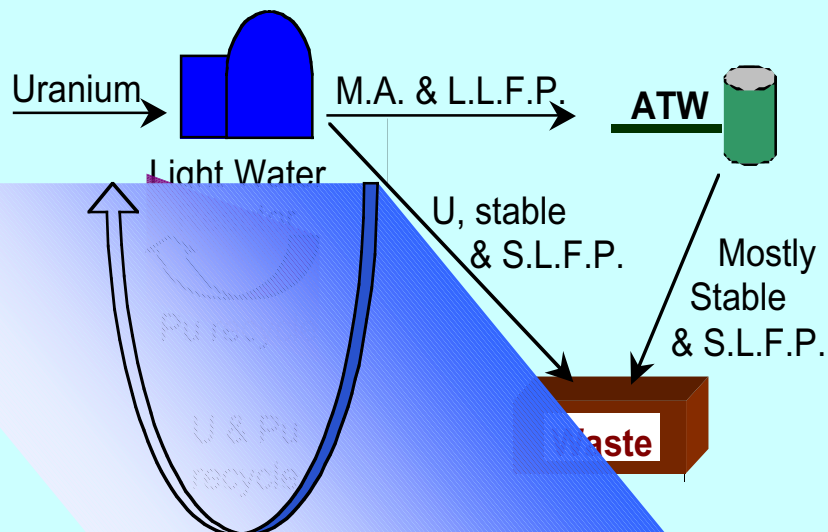
United States: Once-Through Fuel Cycle



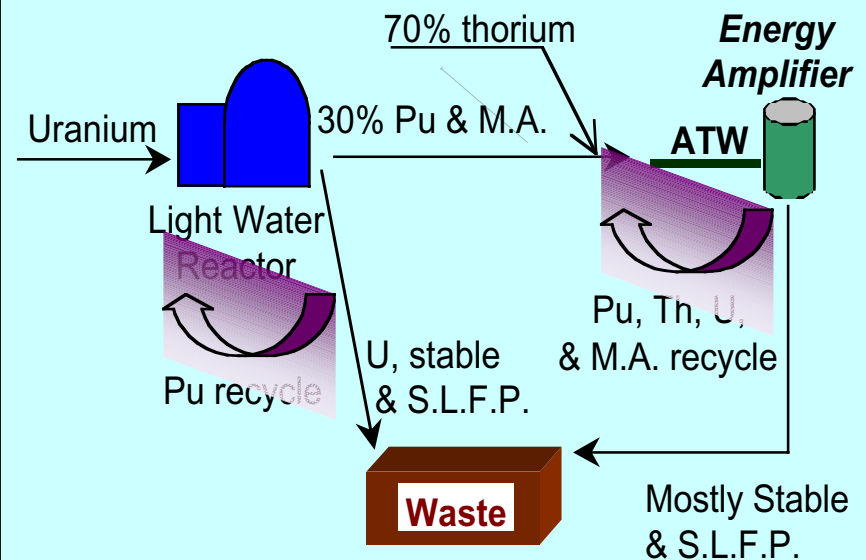
France: Multi-Component Concept



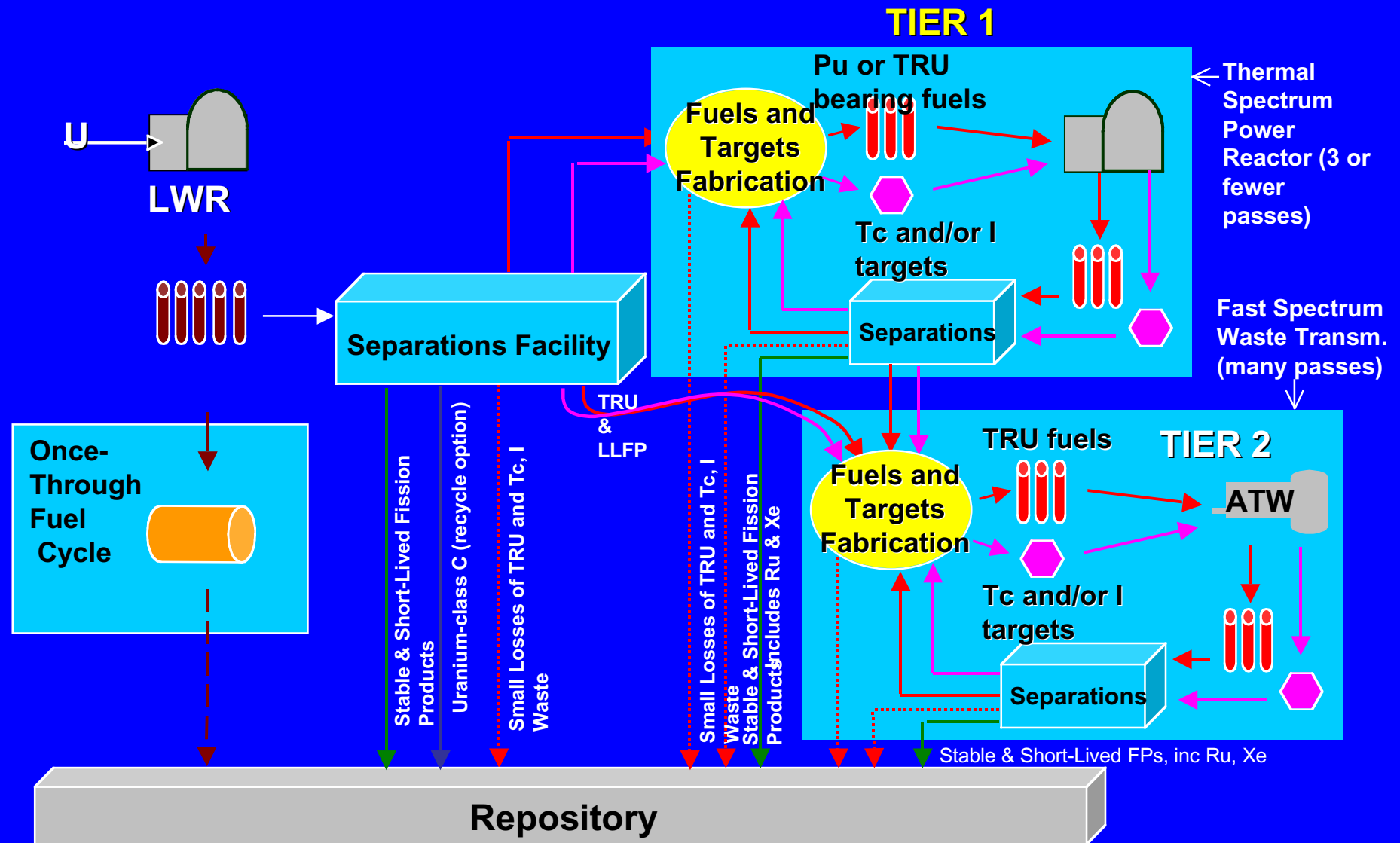
Japan: Double Strata Fuel Cycle



CERN (Spain, Italy, ...): Minimal Scheme



Multi-Tier Approach Using Thermal Spectrum Power Reactors to Transmute Pu May Improve Economics, but Increases Materials Flow Complexities

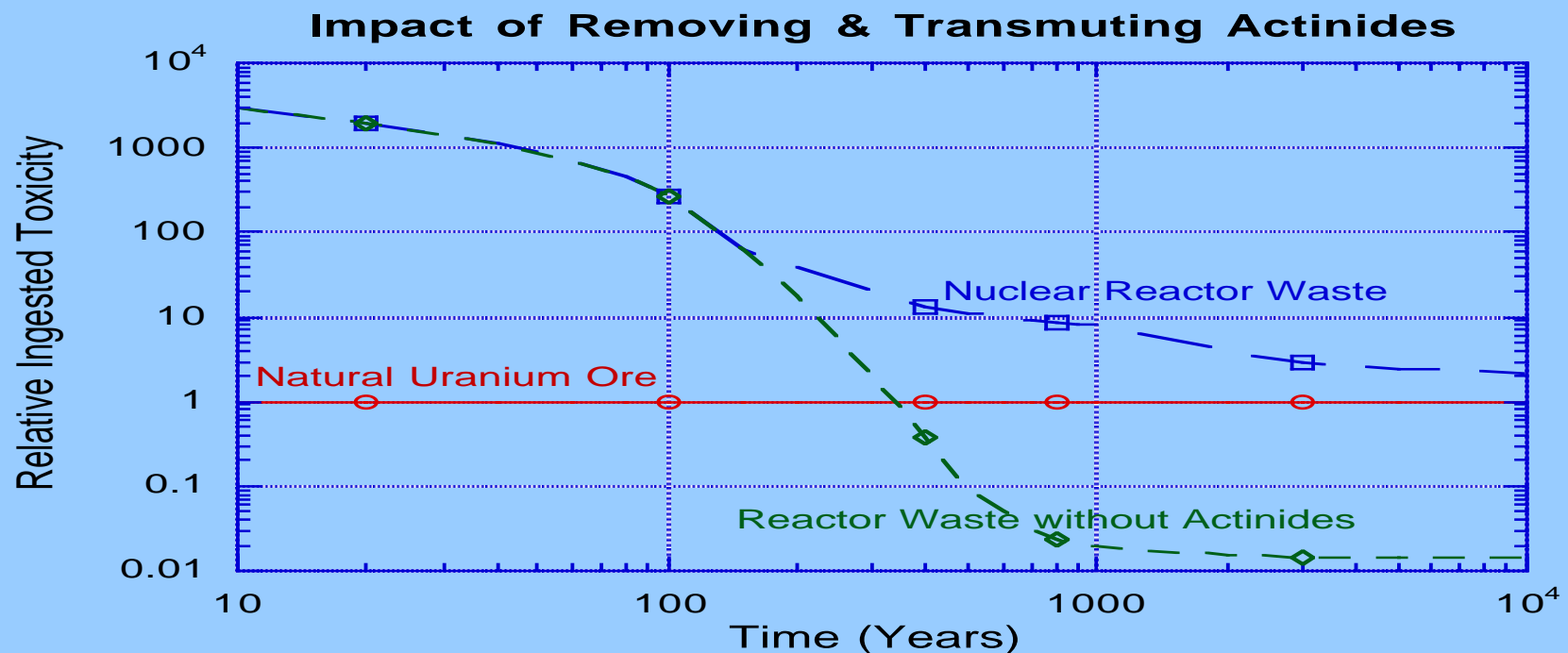


Partitioning & Transmutation are evaluated versus four goals



- ¥ Reduce volume and radio-toxicity of waste
- ¥ Provide benefits to the repository program
- ¥ Increase proliferation resistance of nuclear fuel cycles
- ¥ Support nuclear infrastructure and nuclear future

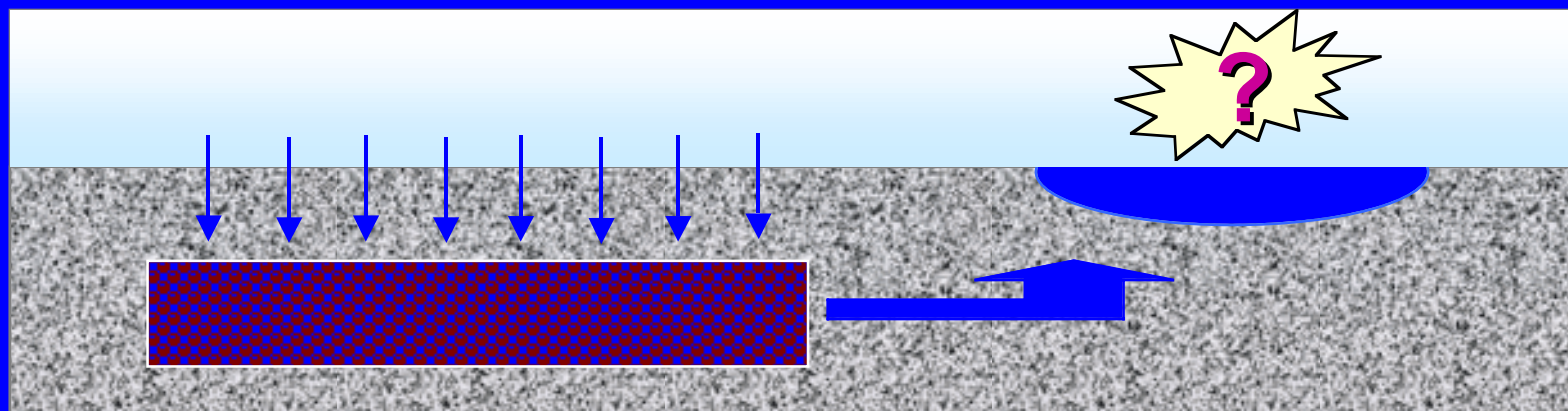
Reduce toxicity of spent fuel within lifetime of man-made containers and/or barriers (a few millennia)



Reduce maximum long-term dose

¥ to future inhabitants by

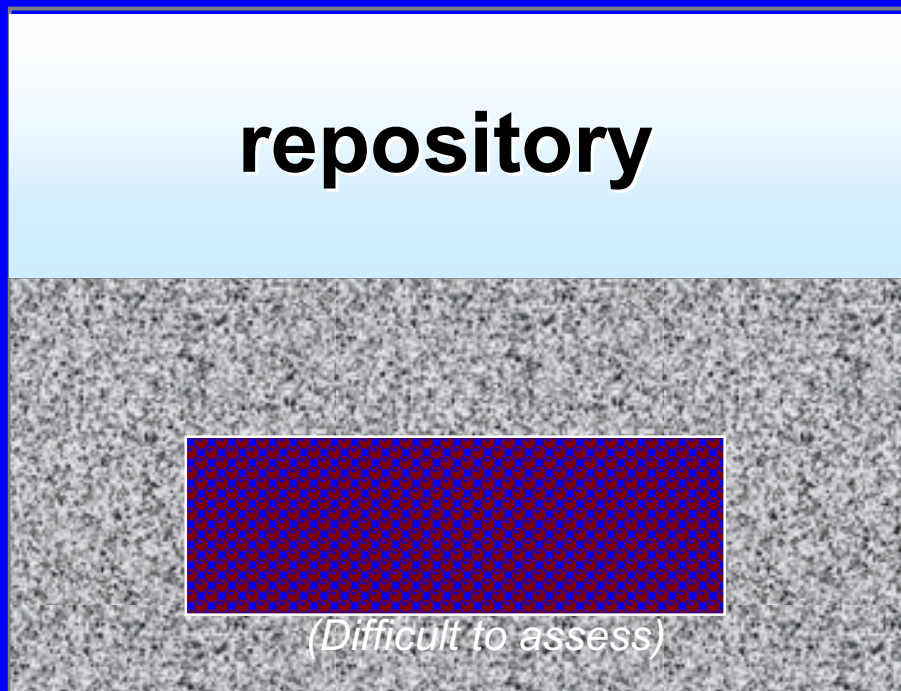
- transmuting mobile elements or
- placing into leach-resistant waste forms



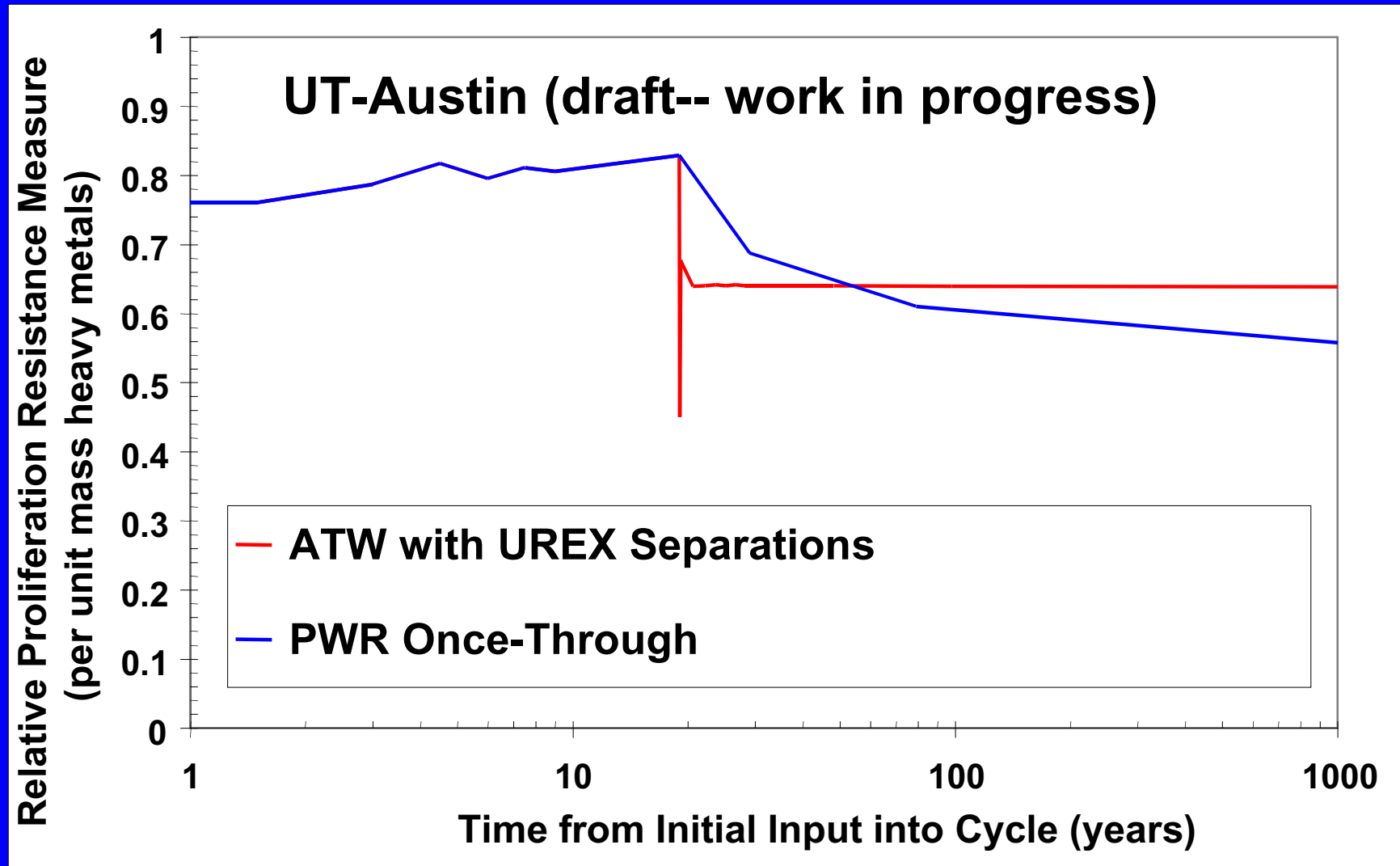
Compare vs. natural background dose

Deplete content/mix of actinides in waste stream

¥ Make it less desirable/attractive than alternate sources of fissile materials



Example: proliferation resistance for two fuel cycles

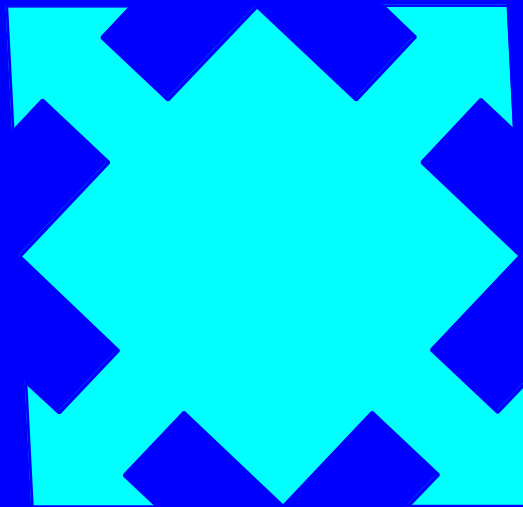


Improve prospects for nuclear energy

≠ Integrate over time & across borders

**Simpler, cheaper
repositories**

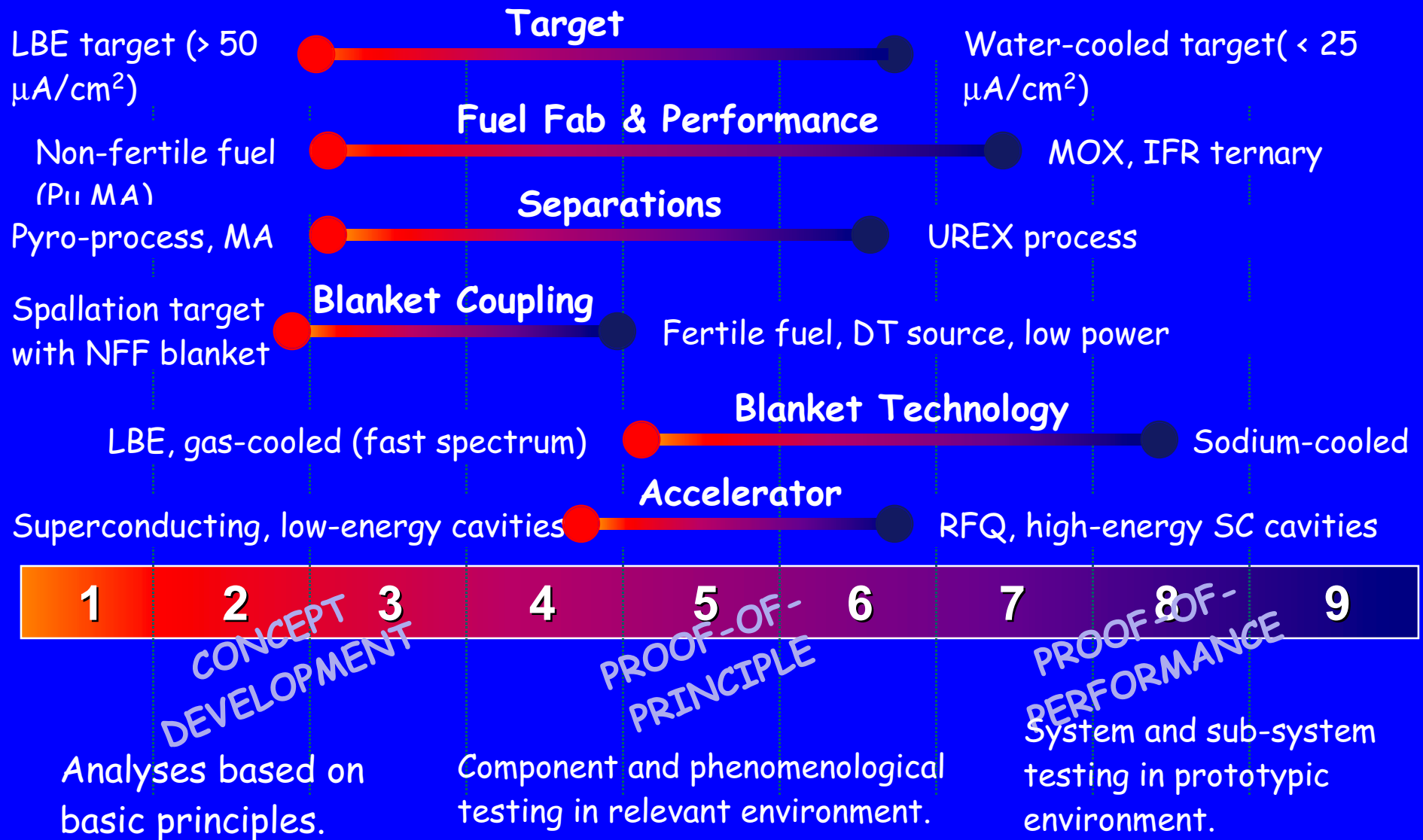
**Near-term
proliferation
risk
minimized**



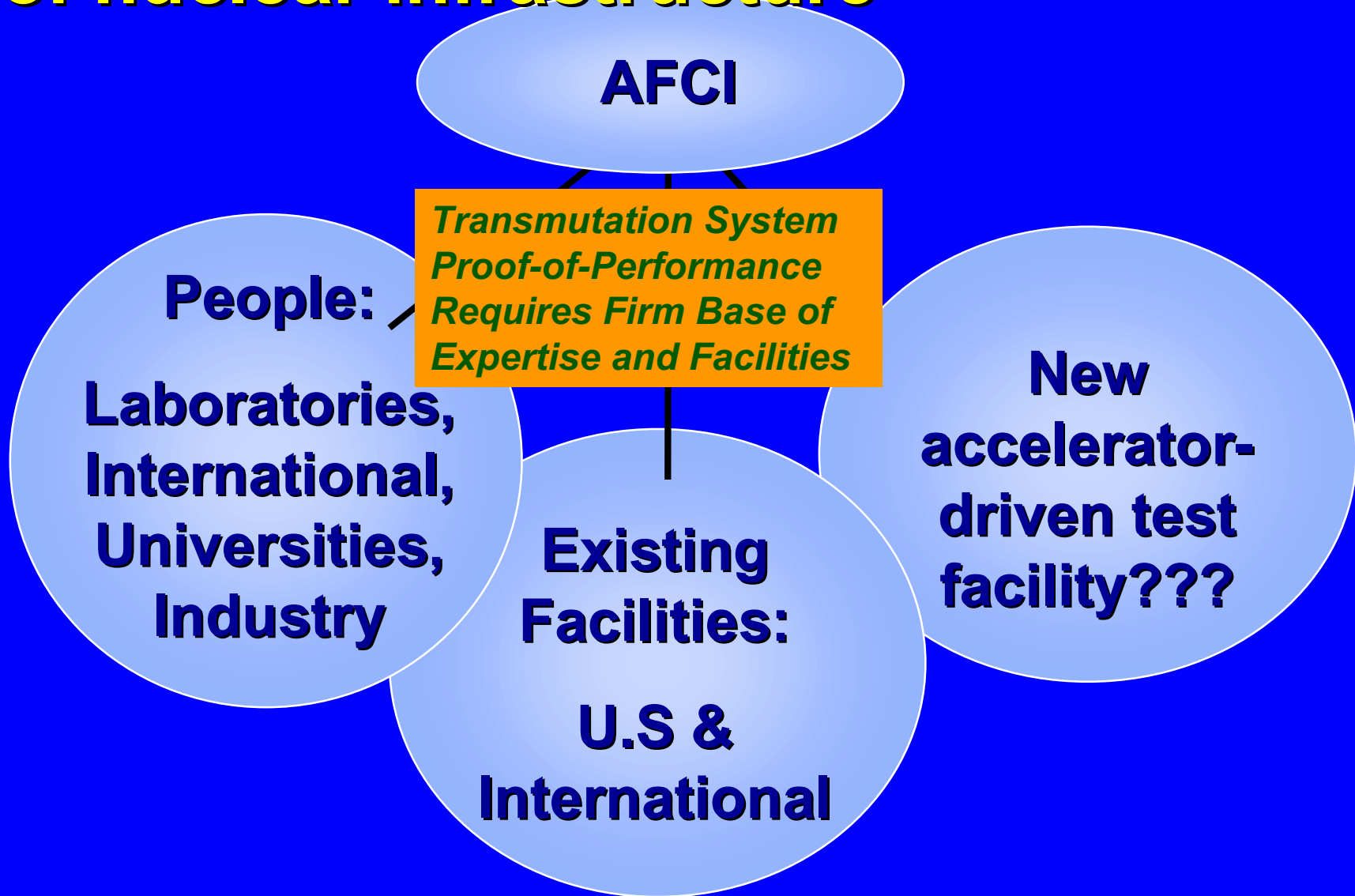
**marginal
cost impact**

**Near-term
ES&H
burdens
manageable**

The existing readiness level depends on the technology area and sub-system



AFCI mission requires optimum use of nuclear infrastructure



Universities are key to AFCl success

¥ Directed university research

—FY01: UT Austin, UC Berkeley, U of Mich

—FY02: add NCSU, U of Ill, U of FL, GA Tech

¥ Fellowship Program

—10 awarded last April

—10 more this year

—Ph.D. next year?

More Universities

¥ UNLV: \$4.5 M, 16 research projects, 3 new faculty, labs, ~50 students

¥ Idaho Accelerator Center, \$1.5 M

¥ AFC academic support growth

—<\$0.5 M FY00

—~\$4 M FY01

—>\$7 M FY02

—\$10 M next year?

**Potential for ten universities, \$10 M,
more than 100 students**

¥ UNLV growth

¥ Idaho State growth

¥ new earmarks?

¥ more AFCL Fellowships

¥ Competitive University Research
Proposal Program in FY02?

¥ Other

Collaboration with the CEA, seven major work packages:

¥ WP 1: ADS Safety

¥ WP 2: Dedicated (Non-fertile) fuels

¥ WP 3: Target and Materials

¥ WP 4: Physics

¥ WP 5: Facilities

¥ WP 6: System Studies

¥ WP 7: Separations

Facilities to provide Proof of Principle and Proof of Performance

Approximate Time Scale:

3 to 5 years

10 to 20 years

Scaled experiments:
LANSCE, TREAT,
MASURCA, MTL,
ATR, PHENIX, BOR60,
Blue Room, Hot Cells

ADTF plus fuel fab
and separations
facilities

Technology Readiness Level Scale:

1

2

3

4

5

6

7

8

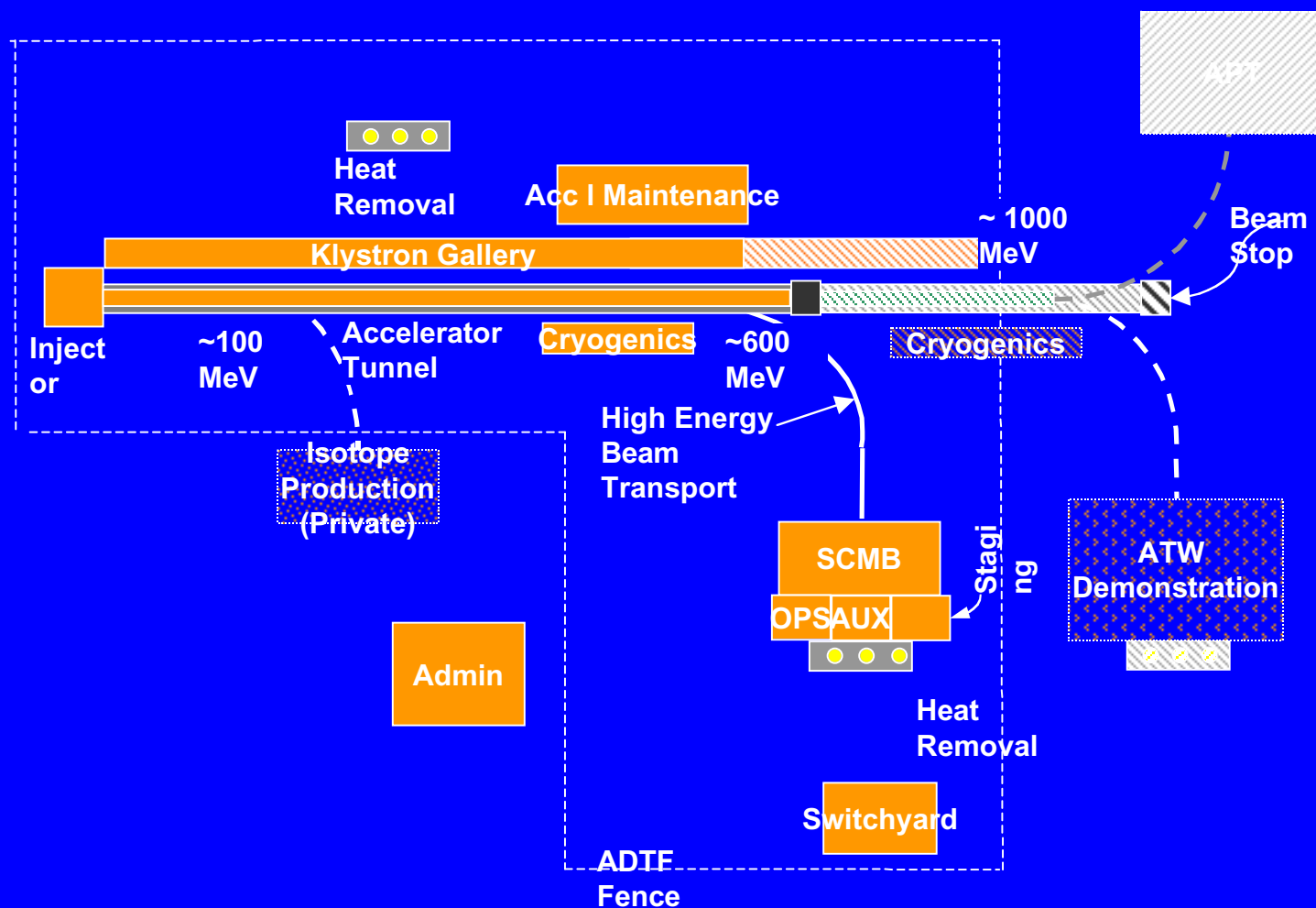
9

Analyses based on
basic principles

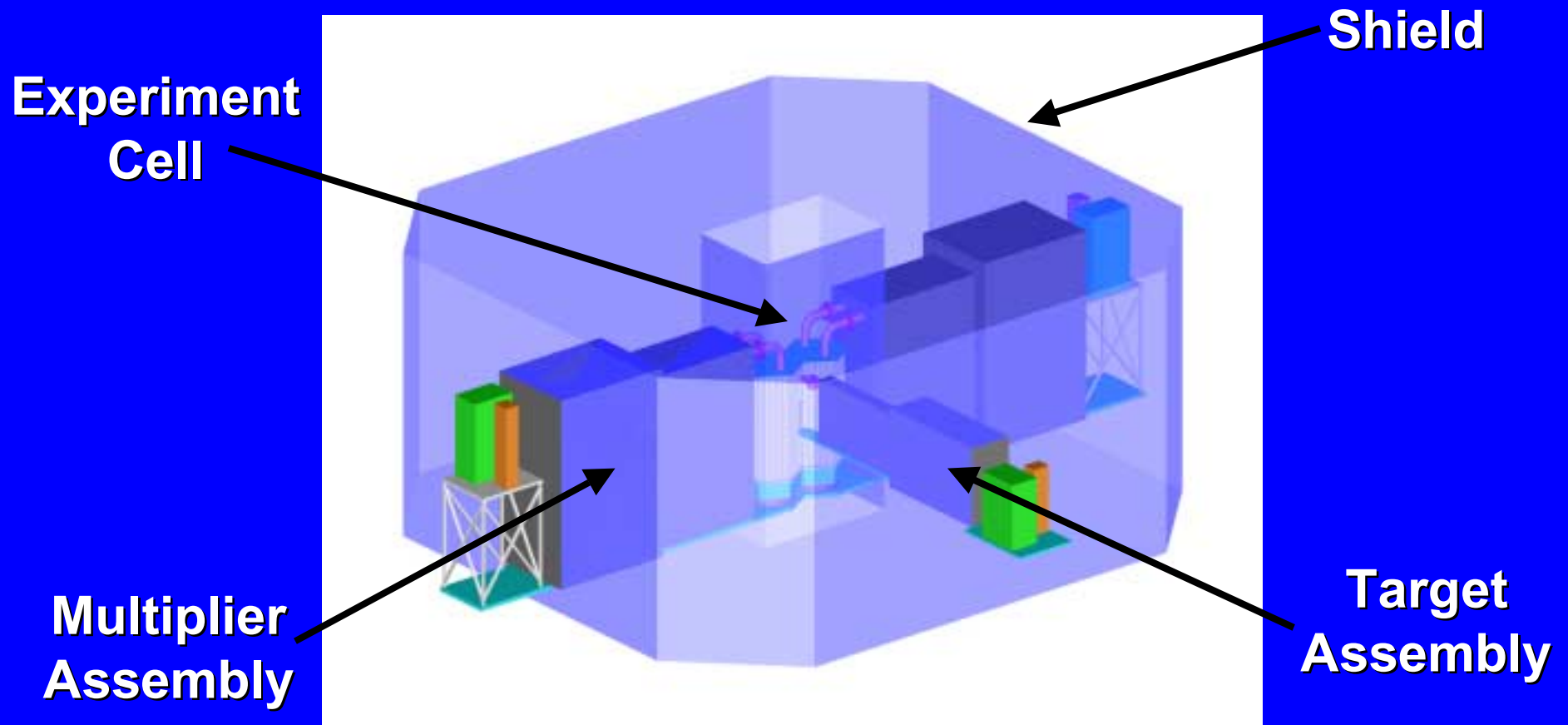
Component and
phenomenological
testing in relevant
environment

System and sub-system
testing in prototypic
environment

Conceptual ADTF layout



Modular concept for target and subcritical multiplier



ADTF benefits

- ¥ Essential reactor constraints can be relaxed in subcritical systems
- ¥ Both steady state and transient modes
- ¥ Accelerator selection optimizes neutron production and proton range
- ¥ Drives 80-180 MW_{thermal} subcritical blanket
- ¥ Demonstration of integrated system

NERAC assessment of transmutation

¥ Phase 1 is complete

**—Goals, exploratory R&D, systems studies,
future directions**

**¥ transmutation can meet the program
goals**

¥ Multi-tier concepts will be examined

**Ref: Report of the Advanced Nuclear Transmutation
Technology Subcommittee of the NERAC, 15 April 2002**

What are next steps? (NERAC ANTT 2002 cont d)

¥ Phase 2

- Focused R&D and systems studies
- 5 to 6 years, ~\$500 M

¥ Phase 3

- Scalable demonstration plant
- 10 to 15 years, \$4 to 7 billion

¥ International collaboration

- Already saved ~\$100 M

Why Invest in the AFCI Program?

- ¥ Public support
- ¥ Good resource stewardship
- ¥ Augments current waste management strategy
- ¥ Brings U.S. back to forefront in nuclear science and technology
- ¥ Spin-off technologies, e.g. medical isotopes, may be as significant as the transmutation of waste

Cons (why not invest?)

- ¥ **Other transmutation concepts exist**
 - difficult to implement, less flexible, and narrower in scope
- ¥ **Uncertainty--success of new technologies always entails uncertainty**
- ¥ **Proliferation?**
 - (R&D should enlighten us)
- ¥ **Cost--worthwhile R&D involves significant investment**

Too costly?

- ¥ Transmutation might mute the critics, John Zink, *Power Engineering*, 1/2002
- ¥ transmutation could remove one public objection
- ¥ technically feasible
- ¥ could become technically practical
- ¥ it all comes down to economics
- ¥ may become cost-effective

The AFCI Program will provide a sound foundation to ...

- ¥ Assess options for transmutation**
- ¥ Develop a test bed for nuclear R&D**
- ¥ Develop isotope production technology**
- ¥ Strengthen nuclear infrastructure**
- ¥ Improve prospects of a nuclear future**

